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Hydrogen from Renewable Energy in Cuba

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Abstract

Hydrogen energy systems based on renewable energy have the potential to meet the energy needs of human societies on a sustainable basis without the negative consequence of local and regional air pollution and global warming, which are associated with our present, fossil fuel dominated energy system. For Cuba the possibility to applied renewable energy for to production of Hydrogen it's very important aspect for the development economic future of the country. The use of hydrogen as a fuel in the future is seen as an alternative for countries without fossil fuel reserves. This paper shows the possibility of hydrogen technologies that use renewable energy sources and their different applications by becoming an emphasis on the use of solar energy.

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Keywords: Renewable Energy, Fuel Cell, Hydrogen. Solar Energy

1.1. Introduction

Energy is the engine that has driven the development of the world. The twentieth century has been a spectacular growth of the economies and living standards globally. The great engine of this development has been the access to energy, given by the availability of oil, with for ease of extraction, transport and storage has been the blood that has fed the body of existing societies, largely replacing previous energy such as water, wind, wood or coal.

The current use of fossil fuels is not sustainable. In the absence of significant changes in the current way we use and produce energy for our future will mean higher costs, because of the shortage of fossil

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fuels supply in areas regularly exploited and extraction of areas in the planet much more challenging since the geopolitical and environmental point of view. Energy security continues to be threatened by interruptions in power supply, accidents in oil extraction, such as occurred in the Gulf of Mexico and disputes over energy resources. If we also consider the use of fossil fuels is the largest contributor to climate change, accounting for about two thirds of all emissions of greenhouse gases, we can argue that all global problems to be faced by human beings in the twenty-first century, there are two that threaten their existence and which are closely related:

- The dependence of the global energy matrix of non renewable energy sources.
- The modification of the planet atmosphere´s chemical composition: climate change.

There´s no energy source absolutely clean, even renewable. All of them cause negative impact on the environment. However, the impact of the Renewable Energy Sources is incomparably smaller than the global disaster caused by the use of fossil fuels that have placed humanity on the brink of unprecedented climate cataclysm, visualizing the use of renewable energy as a key or alternatives to solve the challenges which the world's energy future is currently facing.

1.1. Hydrogen as fuel

Since the early nineteenth century, the scientific community has recognized the hydrogen as a potential energy source. Until now, hydrogen production has been directed largely towards the petrochemical (oil refineries, production of methanol, or basic chemical industry (production of ammonia). However, given the obvious need to find an alternative energy to replace, at least partially and progressively, to fossil fuels in the near future, hydrogen is emerging as the most viable and advantageous option among those that are available, although not without complications. In recent years we have witnessed a dramatic increase in research activity focused on the development of economically viable technologies for hydrogen production, driven by the possibility of incorporating hydrogen as fuel in electric vehicles. Called by "fuel cells", have experimented a strong technological evolution in the recent past, and its efficiency has ceased to be the main obstacle for development in the near future of hydrogen-powered commercial vehicles. In this sense the problems are more focused on the handling and storage of Hydrogen, than the vehicles themselves.

The advantages of hydrogen as an energy source, not only reside in the fact that virtually inexhaustible raw material, the heat of combustion with oxygen (14.19 × 104 kJ / kg) is far superior to traditional fossil fuels such as gasoline (~ 4.5 × 104 kJ / kg) but also its combustion does not produce CO_2, but only water vapour, making it an ideal candidate for reducing the "greenhouse effect". While this last statement is true, it is necessary to qualify its validity, since current commercial methods of hydrogen production necessarily imply the use of fossil fuels (96%), generating significant amounts of pollutants mainly carbon dioxide (CO_2), the following graph shows the global production of hydrogen and as you can see only 4% of the present production of hydrogen is by the electrolysis of water, stemming primarily from natural gas, oil and coal [1].

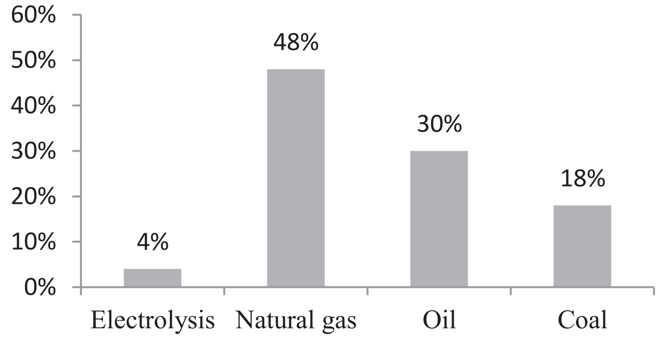

Fig.1. Origin of hydrogen currently produced worldwide.

Current alternatives for hydrogen production are diverse; admitting many centralized and decentralized schemes, the following figure shows different ways to obtain hydrogen, and the different sources of energy that can be used both renewable and non-renewable.

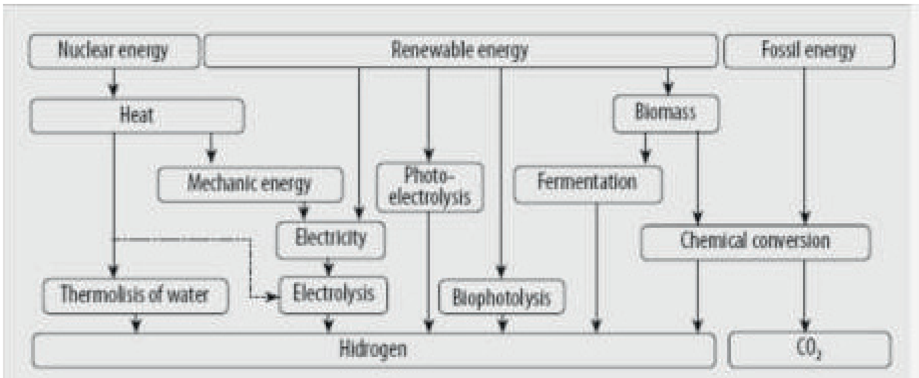

Fig.2. Hydrogen production methods.

Unlike coal, gas and oil, hydrogen is not a primary energy source but an energy carrier, which is first produced using another energy source. The hydrogen can be stored as a fuel to be used in transport and distributed generation of heat and electricity using fuel cells, internal combustion engines or turbines, may also be used as a means of storage of electricity generated from resources intermittent renewable such as solar, wind, wave and tidal. Therefore, it provides a solution to one of the great themes of sustainable energy, the annoying problem of supplies intermittency. In addition, the hydrogen produced locally allows the introduction of renewable energy in the transport sector, offers potentially large economic benefits and energy security and the benefits of an infrastructure based on distributed generation. This is the key element of the energy storage capacity of hydrogen which is the powerful link between sustainable energy technologies and sustainable energy economy, as a rule, under the generic term "hydrogen economy".

Looking forward to a future based on sustainable development, hydrogen energy carrier, produced from renewable energy sources, is becoming more important. And in this field, the hydrogen produced with solar, wind and biomass use are presented as a suitable way to store, in the form of chemical energy, energy from the sun directly or indirectly.

Cuban energy matrix is now dependent on fossil fuels, and it is known that the fuel reserves of Cuba are insufficient, it is necessary to increase the presence of technologies that use renewable energy sources in this energy matrix. It is proposed by many authors that hydrogen as an energy carrier can become the substitute for oil and it´s visualized for our country that obtaining it using renewable energy sources is an alternative.

1.2. Renewable energy sources in Cuba.

Cuba has 11.2 million inhabitants, 97.3% of the population has access to electricity. In 2011, 96% of electricity was generated from fossil fuels, it took 14 268 tonnes of oil equivalent, which 63% was imported [2], however the country has a significant potential for renewable energy sources that can be employed for the electricity generation while contributing to protecting the environment and reducing greenhouse gas emissions [2].

Every square meter of Cuban territory receives daily solar energy amount equivalent to one pound of oil. On each square meter of the same annual average daily incident, a number of solar energy approximately equal to 5 kWh. This represents about 1800 kWh/m2año. Solar radiation in Cuba is usable throughout the year and throughout in form of bioenergy or biomass, as hydropower, wind or directly converted into thermal energy or electricity.

At the end of December 2010 the renewable energy technology facilities that produce electricity (wind farms, hydroelectric and cogeneration units of the sugar mills), contributed 570.4 GWh (about 13 days of generation of the country) and replaced 146 513 tons of oil. At the end of 2011 in Cuba were 26814 plants using Renewable Energy Sources, 9624 photovoltaic systems, solar heaters 6447, 8677 Windmills, 554 biogas plants, 173 hydroelectric facilities, 608 brick kilns with forest biomass production and 4 Parks Farms. In 2013 envisions a scenario characterized by an increase of the technologies that employs renewable energy sources, today there are already 34 658 facilities, 7844 more than in 2011, which can be seen in Figure 3.

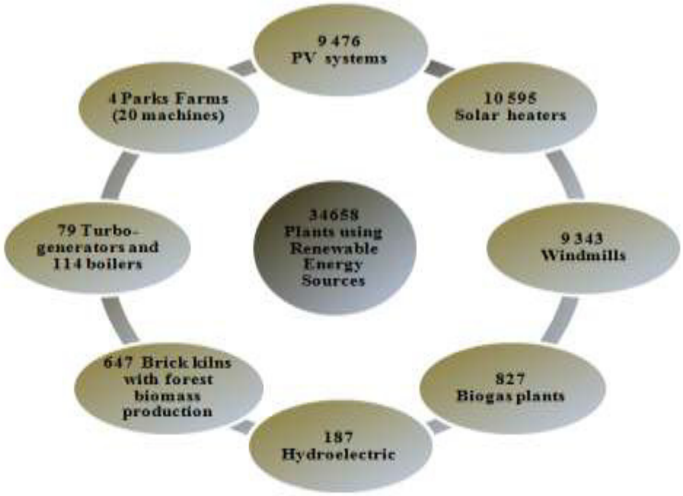

Fig.3. Renewable energy installations in Cuba today.

Red connected photovoltaic systems in Cuba are scarce, representing a minority compare to stand-alone photovoltaic systems. Contribute to its development as massive program is a central objective in order to achieve the necessary energy independence in the country, for that reason is already operating a 1MW

Photovoltaic Park in the province of Cienfuegos and as development project is proposed the construction of a 10 MW Photovoltaic Park located in 7 areas of the country: Guantanamo, Santiago de Cuba, Camagüey, Cienfuegos, Villa Clara, Isla de la Juventud and Havana. These projects aim to reach 15.5 GWh annual electricity generations for a period of 25 years, equivalent to annually replace approximately 4948 tons of fuel [2].

Identified hydro potential energy is 848 MW with estimated average annual generation than 1900 GWh. This would save more than 450 thousand tons of fuel compared to the generation of generators leaving the atmosphere to emit 1.3 million tons of CO_2. At short term it is evaluating projects which will contribute 55MW. Six deep sea areas are surrounding the island. The sea temperature differences using OTEC technologies are of obvious application. The experience Boucherot and Claude in 1930 in the Bay of Matanzas is a global milestone. The north coast bays have significant potential to harness ocean undercurrents, but still it advances and deepens the studies.

Among the potential of renewable energy sources on the island is identified wind power, which represents 25% of total renewable energy potential of the island, which is equivalent to 2100 MW, Figure 4 shows the sites with the highest wind potential identified in 2011 and on which there are 13 projects under evaluation.

Fig.4. Wind potential in the island. 2011.

Regarding wind energy it has identified the potential to generate 633 MW with 13 wind farms, working on the construction of a 51 MW wind farm in Herradura Beach, Province of Las Tunas, which will consist of 34 wind turbines of 1.5 MW, which 153 GWh/year must provide what amounts to the replacement of 40 163 tons of fuel.

Considering that 25.7% of the country is covered by forests, or about 2825.9 hectares, and Marabou (invasive plant) are covered about 1649 acres, together with forest biomass sugarcane biomass also represent a potential to keep in mind when we talk about renewable energy sources in Cuba. Biomass gasification is not a new technology, its use increased after the global energy crisis of the 70s. In Cuba there is a program for the use of forest biomass that includes the installation of gasification plants connected to the internal combustion engine to produce 1MW of electricity in the community Melvis, 50 kW in the community of Crocodile on the Isle of Youth, in Matanzas in Indio Hatuey 22 kW and 40 kW Santiago de Cuba. Other examples are the Bioelectric 20 MW in Central Jesús Rabbi in the province of Matanzas and Bioelectrical plant of 60 MW in the Central "Ciro Redondo" in Ciego de Avila.

At present run on 20 biogas industrial plants obtained from pig waste, 6 for power generation and 14 for other uses. In Isla de la Juventud a gasification plant of 0.5 MW woody biomass, gasification plants in

Macurije and Pons sawmills in the province of Pinar del Rio. 6532 was produced and installed hot water heaters with solar energy and windmills pump 1423.

From the above it can be seen that the renewable energy sources in Cuba have a high potential, mainly solar, wind and biomass. It works for having an energy matrix independent of fossil fuels, being a need the use of technologies that exploit renewable energy sources for electricity generation and the search for alternative fuels such as hydrogen could be. Being above a government priority which remained expressed on December 11 when it was created a government commission responsible for drafting the proposed policy for the use and the prospective development of renewable energy in the period from 2013 to 2030, which has among its objectives:

1. Reducing dependence on fossil fuels with consequent effect on the country's energy independence.
2. Reduce the high cost of energy that is delivered to consumers, due to fuel prices and the inefficiency of the electrical system that directly affects the competitiveness of the economy as a whole.
3. Contribute to environmental support, given that the country's energy production from fossil fuels is a major source of environmental pollution.

2. Hydrogen from Renewable Energy Sources in Cuba.

To Cuba there´s no sense to base its production of hydrogen from fossil fuels, for this reason we will focus on the method of producing hydrogen by electrolysis of water, obtaining the necessary electricity using technologies that exploit renewable energy sources, including solar, wind and biomass, which are the most promising sources at short-term development in the country.

2.1. Electrolysis of Water

The electrolysis of water was discovered at the dawn of the first industrial revolution, in 1789 by German scientists Diemann and P Van Troostwijk. It consists in the decomposition of water into its constituent elements (hydrogen and oxygen) to the passage of an electric current between two electrodes within a body of water. The overall electrochemical reaction is as follows:

$$H_2O(l) + electric \quad energy \rightarrow H_2(g) + \tfrac{1}{2} O_2(g) \qquad (1)$$

The equipment where electrolysis occurs is called electrolyser, its goal is the production of hydrogen, oxygen being a by product of the chemical reaction and susceptible to be exploited. Generally, electrolyser consists of electrolytic cells built together and each formed by:

- Two electrodes, cathode and anode through which a current is applied continuously.
- The electrolyte used determines the type of electrolyser, the most used are acid electrolytes (solid state electrolytes) and alkaline (liquid electrolyte) formed by water and a substance that helps the transport of ions from the cathode and anode of the electrolyser.
- A diaphragm or membrane restricts the passage of compounds between the cathode and anode of the cell, preventing the mixture of hydrogen and oxygen produced.

The Figure 5 shows the schematic of an electrolytic cell of an alkaline type catalyst where can be observed the different components discussed above.

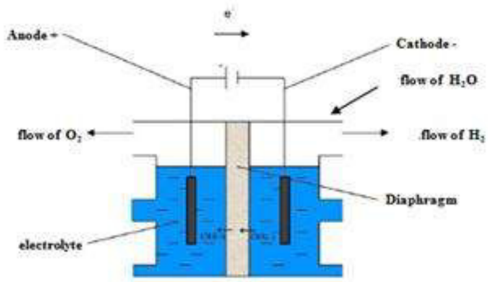

Fig.5. An electrolytic cell scheme of alkaline electrolyte.

The electrolytic cell is subject to a potential difference between the electrodes, this potential difference between the electrodes together with the operating temperature of the electrolyser will define the electrical current flow through it. Hydrogen production is directly related to the electrical current flowing between the electrodes of the electrolytic cell, to the same potential variation with increasing temperature of operation will increase the current intensity, increased hydrogen production [3].

The acid and alkaline electrolysis are the most used in current commercial electrolysers. The kind of electrolysis depends only about the electrolyte type used in the electrolytic cell. The alkaline electrolysis is the most widely used commercially and the most used in the integration facilities renewable energy and hydrogen.

Depending on the mode in which the electrolytic cells are electrically connected to each other, one can generate two different configurations of electrolysers: the unipolar when the cells are connected in parallel and when the bipolar cells are connected in series, see Figures 6 and 7.

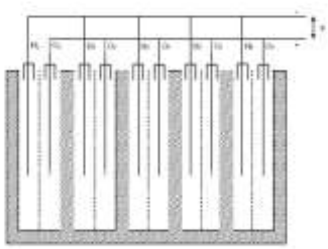

Fig.6. Electrolyser unipolar.

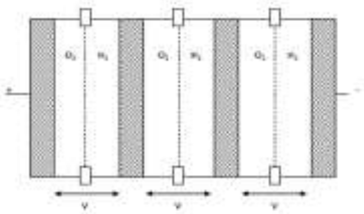

Fig.7. Electrolyser bypolar

Employing either configuration determines the behaviour and pressure at which hydrogen is generated in them. Unipolar are easier to build, operate, maintain and use of the water supply pump to be generally lower operating pressure less electrolyser, these electrolysers produce hydrogen at low pressure and for the same production of hydrogen occupy more bipolar space. The electrical connection of them is also more complex because each cell must be powered independently.

Bypolar have the advantage that they can be pressurized, causing hydrogen pressure, which increases the energy efficiency of the installation by not needing compressing equipment hydrogen at low pressure. Besides the electric connection of the cells is easier since only the source is connected only to the ends. In return, the power consumption of the water pump is higher as the operating pressure is higher and has parasitic electrical losses; need greater protection for electrical potential difference between the terminals of stack is large.

When hydrogen is required at atmospheric pressure is chosen unipolar electrolysers when needed while hydrogen pressure (30 bar) are used bipolar configurations. From the standpoint of purity hydrogen obtained in alkaline electrolysers, hydrogen is obtained with a purity of 99.8% by volume; the rest is water vapour and oxygen.

2.2. Hydrogen production by solar energy.

The methods of hydrogen production with solar energy are grouped into three major groups, the photochemical processes, electrochemical and thermochemical combination may exist between them as photoelectrolysis, electrolysis of steam at high temperature [9].

Given the characteristics of Cuban solar radiation, diffuse radiation which is worth approximately 40% of direct normal radiation and there are an average of 10 cloudy days per month, the methods that make use of concentrated solar energy will not be analyzed in this article, such as high temperature electrolysis of water vapour, supplying heat and electricity from cylindrical-parabolic collectors, parabolic dishes, central tower facility, which method is known to address the electrolysis of water at room temperature has the advantage of requiring a lower power input. Thermochemical methods including direct thermolysis include water-based thermochemical cycles reducing metal oxides using concentrated solar radiation as a high temperature heat source to perform the endothermic reaction.

Cuban In the present scenario most likely displayed the production of hydrogen from water electrolysis at low temperature (room temperature) using as a source of electrical energy needed in the process solar photovoltaic and wind energy, mainly. No discarded given the potential for forest and sugar cane biomass that has the island and research progress in the use of biomass gasification.

3. **Integrated systems for hydrogen production**.

Integrated systems are intended for the production of hydrogen on a large scale for subsequent use in the industry, as fuel in alternative internal combustion engines (AICE) for electricity generation or use directly as a fuel or fuel cell using the transport sector.

Figure 8 shows a scheme with the basics of integrated system for production of hydrogen, we see it as the wind farm and / or the photovoltaic field would provide the necessary power to the electrolyser for hydrogen production. In this scheme the input electrical energy of the turbine or wind farm and photovoltaic solar contribution need not be used only for the production of hydrogen, but also can contribute to the production of conventional power in situations that required. When the tank or hydrogen storage tanks reach capacity, the electrolyser is disconnected and reconnected until it has reduced the presence of hydrogen in the tanks.

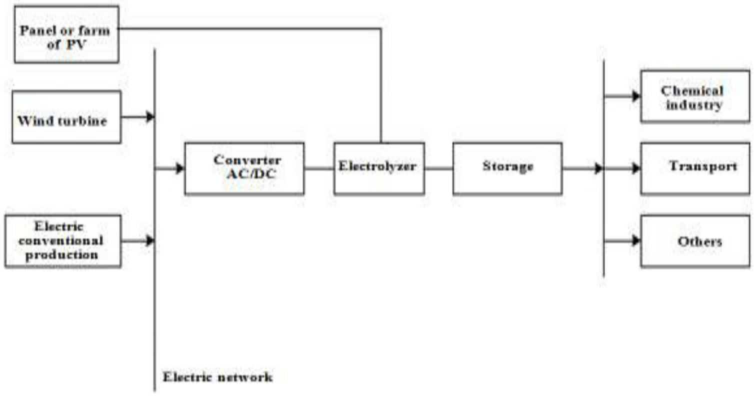

Fig.8. Basic integrated system for production of hydrogen schema.

Hydrogen as a chemical energy storage allows the coupling between energy production and consumption and improves the management in electrical systems for generation based on renewable energy. When the electrical power produced by a wind farm or PV is higher than the demand of the network, the electric power goes to an electrolyser which produces hydrogen by electrolysis of water, it is stored therein and the oxygen is vented to the atmosphere. When the network demand is greater than that produced, the stored hydrogen is consumed for electricity production adjust to the need, this transformation can be done by burning hydrogen in Alternative Internal Combustion Engines uninterruptible power consumption or by in proton membrane fuel cells (PEM).

It can also operate the integrated system so that during periods when electricity is sold at low prices, the energy produced is sent to the electrolyser to produce hydrogen, in periods where energy is traded at high prices, and then the hydrogen is converted into electrical energy by means discussed above. This helps to maximize the benefits of using renewable energy sources and to better manage the intermittency of the renewable resource.

A scheme that allows use hydrogen as energy storage system coupled to allow the production of electrical energy demand is shown in Figure 9.

Figure 10 shows an integrated scheme but for the electrification of isolated systems.

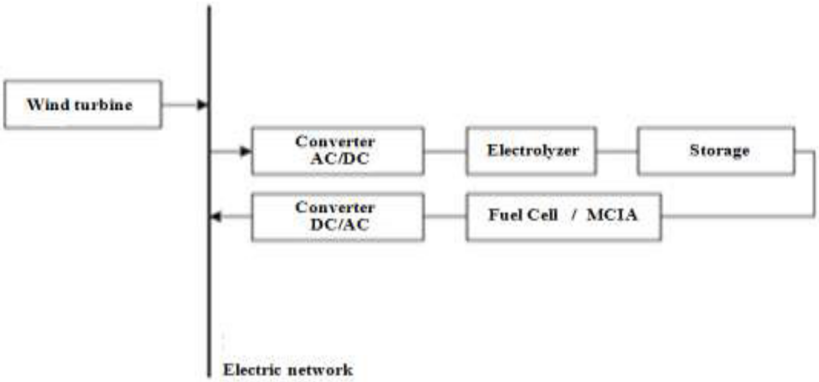

Fig.9. Schema of a integrated system for matching the production and electric power demand.

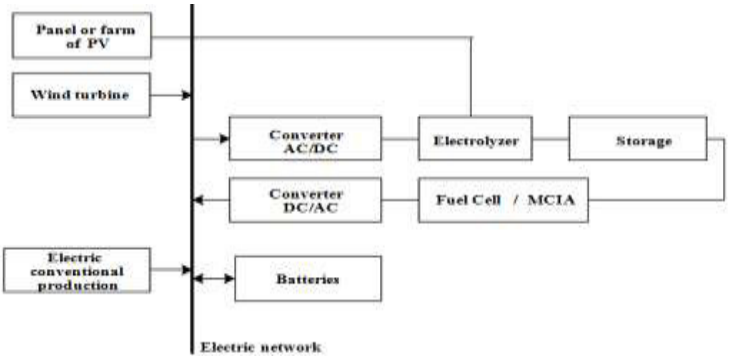

Fig.10. Scheme of a integrated system for isolated electric nets.

Conclusions

Through this paper aims to show the possibility that the hydrogen produced from solar, wind and biomass in the current Cuban context, in addition to becoming an alternative fuel for power generation and other industrial applications or in the transport sector, are key elements of Cuban society development. Integrated systems of renewable energy sources, wind, solar and hydrogen are displayed as an alternative for electricity production to Cuba and as energy storage elements, allowing avoit the intermittent energy production using renewable energy sources.

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